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13. ABSTRACT (Maximum 200 Words)

Despite advances in the last decade, the radiographic diagnosis of breast cancer remains uncertain. Of the annual 600,000 cases referred for biopsy by mammograms each year, 400,000 are unnecessary, costing $2 billion annually. The diagnosis of breast cancer in young women and women with silicone implants continues to be difficult. Accurate detection of small breast tumors (2-3 mm) is still to be achieved. Positron emission tomography (PET) has the potential to reduce this high healthcare cost, unnecessary painful anxiety, and to improve diagnosis and survivability for women of all ages. We have developed the detector and electronic technology for building an ultrahigh resolution PET camera. We propose to use such technology to construct an ultrahigh resolution PET that has a dedicated breast-diagnosis mode that has 13-26 times higher detection sensitivity than regular PET and an ultrahigh image resolution of 2.5mm compared to the 4.5-6 mm in today's PET cameras. We have already developed a scaled-down engineering prototype PET to confirm the feasibility that 2-3 mm tumor can be detected accurately. We propose to construct a scaled-up clinical version of the design so that it can be used for clinical human trials to confirm the clinical utility.

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INTRODUCTION

Despite advances in the last decade, the radiographic diagnosis of breast cancer remains uncertain. Also, the diagnosis of breast cancer in dense breasts continues to be difficult, whether the density is a result of fibrocystic diseases or young age. Accurate detection of very small breast tumors (2-3 mm) and small metastases, which is essential for survival and breast conservation, is still to be achieved. Positron emission tomography (PET) has the potential to improve in these areas as PET images physiologic differences between tumor and normal tissue, providing > 90% sensitivity and >95% specificity in many recent studies. It also eliminates imaging difficulties for women who have silicone implants and dense breasts, which have negligible effect in PET; hence, PET is useful for high-risk young women and patients with implants.

However, for breast cancer diagnosis, there are technical limitations in current PET cameras that are designed for whole-body tumor staging instead of breast imaging. This goal of this project is to help the development of an ultrahigh resolution convertible-PET design that minimizes the limitations:
(1) A convertible gantry with a dedicated breast mode that has 10-15 times higher detection sensitivity for breast-tumor activities than a whole-body PET
(2) An intrinsic image resolution of 2.5-3.0 mm

BODY

The statement of work or task for this period is as follows:

TASK 1. Developing a PET camera gantry that can be transformed between the whole-body mode and the breast mode (Months 1-30): Design and Construct the mechanical gantry with a power distribution system (Month 2-24).

TASK 2. Fabricating and testing 40,000 small scintillation detectors, and building the detection system (Month 1-24): Produce the scintillation detectors (Month 7-24). Test and quality control for the scintillation detector produced (Month 12-24). Test assembling the detector system with scintillation crystal and photomultipliers integrated together (month 21-24).

TASK 3. Developing the high-speed electronic system, 169 circuit boards (Month 1-30): Design, build and test the fast amplifier boards--48 circuit boards (Month 14-18). Design, build and test the HYPER Anger-positioning electronics—48 boards (month 19-24).
Design, build and test the programmable coincidence-detection board (Month 12-24)

TASK 5. Developing the software and image-process techniques (Month 1-30): Continuously developing the image reconstruction and image processing technique (Month 12-24).

FOR TASK-1:

We have been productive since the funding of this US Army grant that started two year ago. All the tasks scheduled for the period have been accomplished. Much progress has been made in developing this ultrahigh resolution transformable PET camera. In this one year, our research effort have resulted in the submission of peer-reviewed scientific papers; 11 of these 17 papers is already in print or accepted to be published, with the other 6 still in the peer-review process.

The transformable rotating PET gantry design is finished [1,2]. The 3-D mechanical design drawings are shown in fig.1-4. These figures are actual 3-D mechanical drawings ("blue print") with correct dimensions and not just drawings.

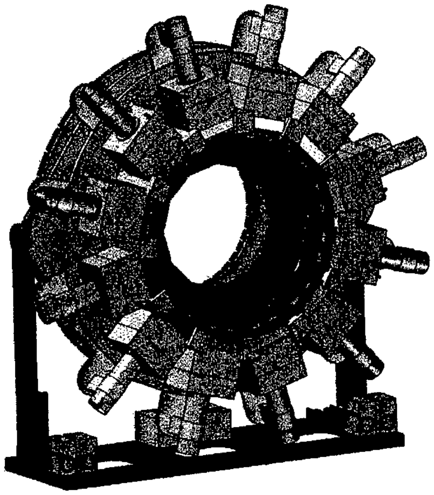


FIG. 1 The PET in whole-body imaging mode

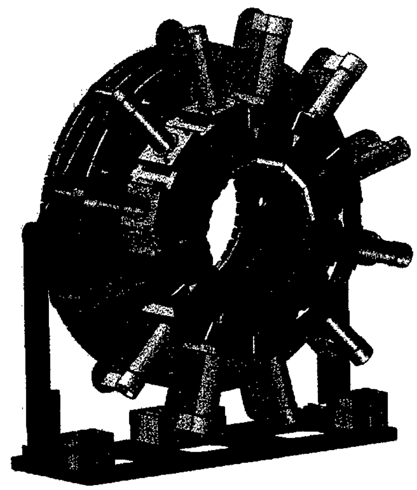


FIG. 2 The PET in breast imaging mode

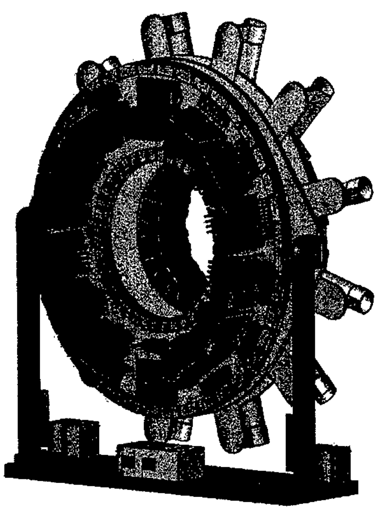


FIG. 3 Back of the rotating gantry carrying the electronics

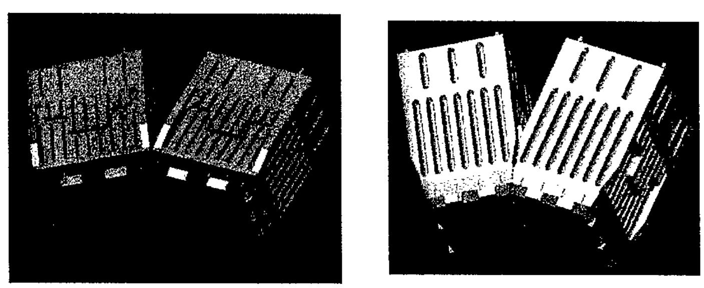


FIG. 4 This shows how two neighboring rectangular detector modules are rotated and meshed into each other so that the same detector modules can create a big detector ring for wholebody imaging and a small ring for breast imaging.

The detail design of the detector module is shown in fig.5 [1,2]. Two such test-modules were constructed with all crystals, photomultipliers, front-end fast amplifier and control electonics incorporated (fig.6). The 2 test modules were mated together accurately mechanically with no gaps between the two detector modules to facilitate the body-breast conversion (fig.7).

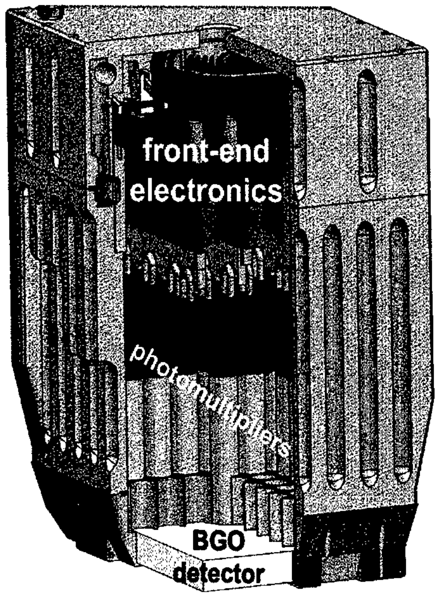


FIG. 5 Internal design of module

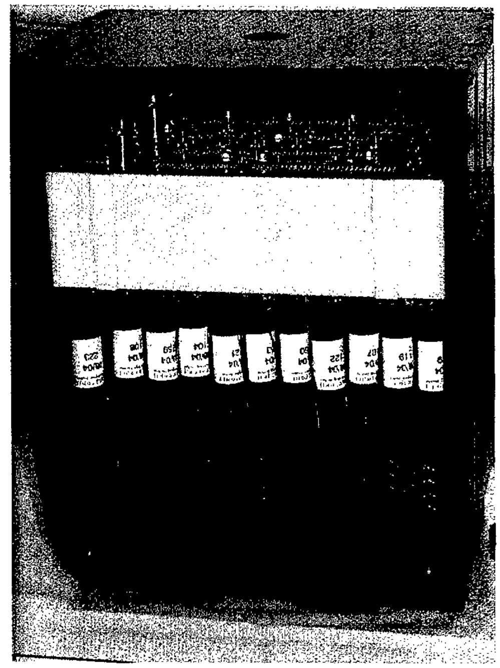


FIG. 6 Module construction

FOR TASK-2:

All the position-sensitive BGO detector blocks with a total of 40,000 individual crystals have been constructed [3-4]. Each detector module carries 66 detector blocks and each block has up to 64 crystals. Construction of the position-sensitive detectors has been the most labor intensive part of the project. A constructed detector bank, 66 blocks 3168 crystals, is shown in fig.8 [3-4].

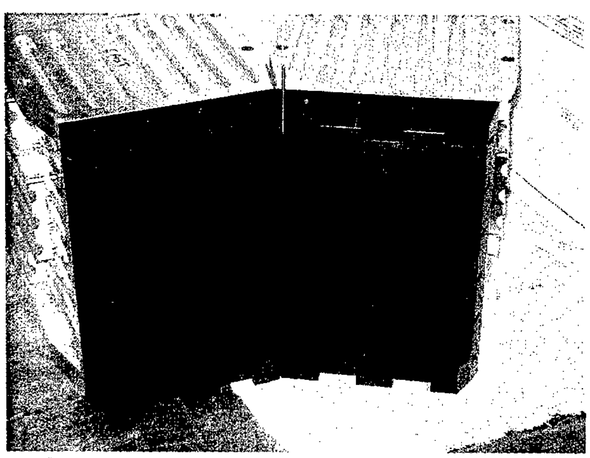


FIG. 7 Mechanical mating of two test-modules

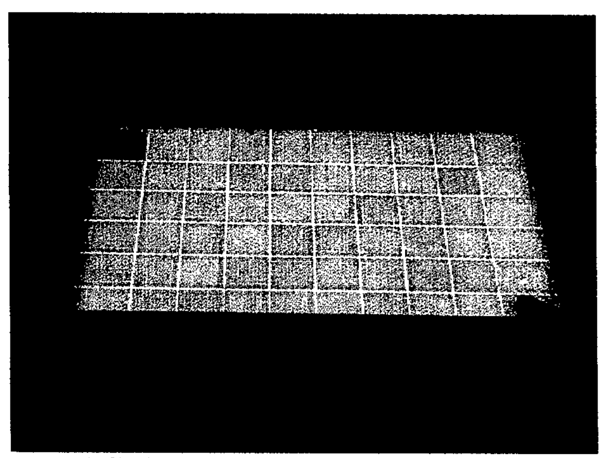


FIG. 8 A detector bank with 3168 position-sensitive detectors

The detector-position decoding of the constructed detector blocks were tested for the 40,000 position-sensitive crystals [3] using the prototype electronics we designed and constructed for this PET camera. The crystal-position decoding test results have been excellent (fig.9).

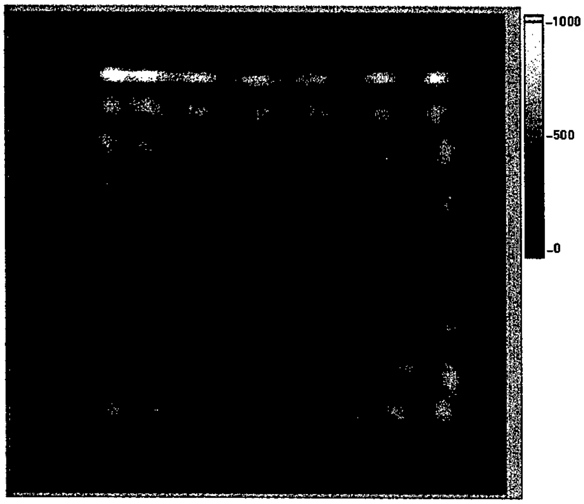
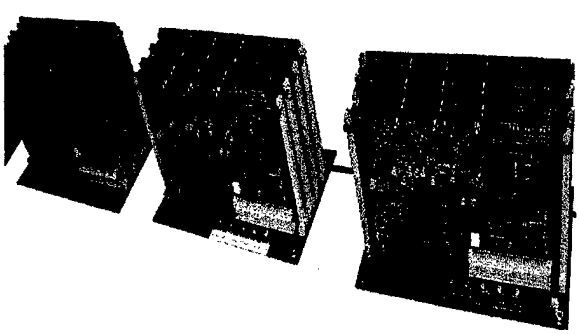


FIG. 9 Crystal-position decoding results

FOR TASK-3:

Electronic Design and Construction

The patented high-speed pileup-recovery front-end electronics and decoding-electronics (HYPER) have been designed and all 12 sets of HYPER have been constructed (fig.10) [5-8]. This front-end electronics were tested and they performed well and were used to obtain the results shown in fig. 9. The coincidence-timing and data sorting electronics has also been developed and built for this transformable PET (fig.11) [9].



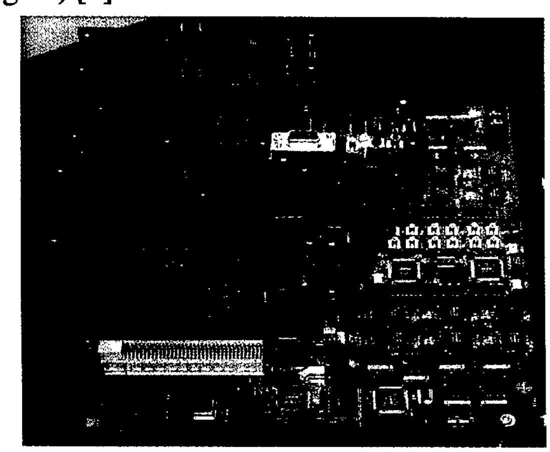
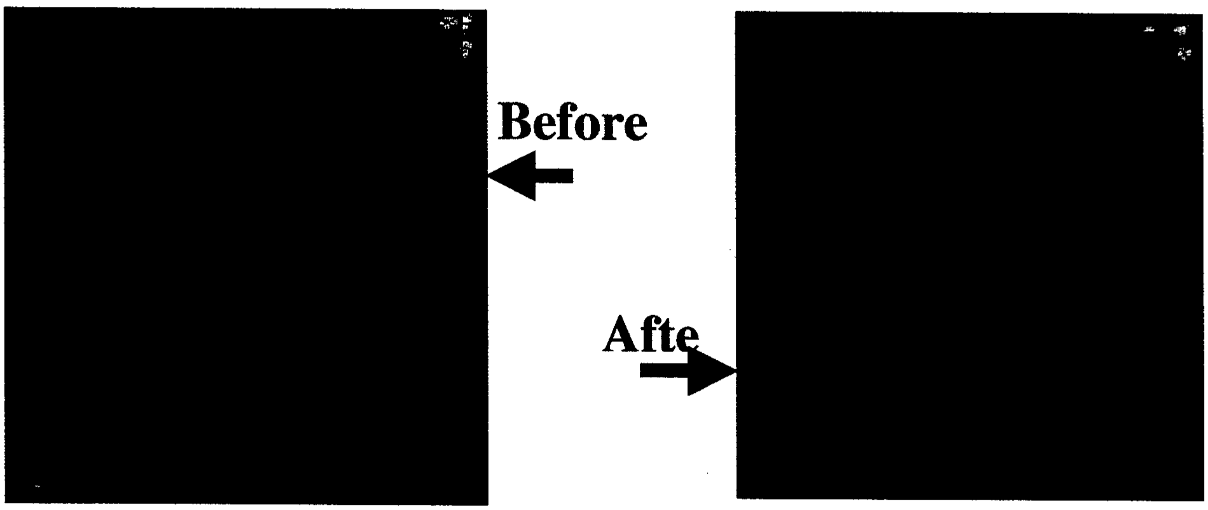


FIG. 10 3 of the 12 sets of HYPER electronics.

FIG. 11 Coincidence electronics

We have done partial testing on it. The full test cannot be performed until the entire system are put together. The partial test on processing dead-time and event-sorting throughput showed that the circuit can process a maximum of 36 million single-events per second hitting the whole detector system and process 5 million coincidence-event per second. Both of these figures are much higher than most clinical human studies.

We also developed a high-speed system-wide detector-tuning system for this PET camera and this BGO-detector-tuning system should take 1-2 minutes to retune all 40,000 detectors instead of the 4-6 hours in current commercial systems, thereby allowing the whole PET to be re-calibrated for every patient to insure optimal imaging quality for every patient, instead of 1-3 months in current practice. This tuning system (using internal LED light) has been developed and tested and recently submitted for journal publication. Test results showed that all 40,000 detectors in the camera can be recalibrated in 1 minute [10-11]. The detector-position-decoding test "before and after tuning" was excellent (fig. 12).



Before tuning After tuning

FIG. 12 Before tuning, crystal positions were moved to the right and caused position-decoding errors. After tuning, the crystals positions were restored to the original positions

Because of the ultrahigh image resolution of the system, we are developing a breathing-cycle gating system to correct for the patient breathing moving. This system used a sensor in the patient's nostril air flow and gating electronics to correct for the patient breathing movement (fig.13). A paper has been submitted for journal publication [12-13]. Test results of the system, using our existing prototype PET, showed that this gating-system increased lesion uptake in the image by an average of 2.2 time for 3-5 mm lesions.

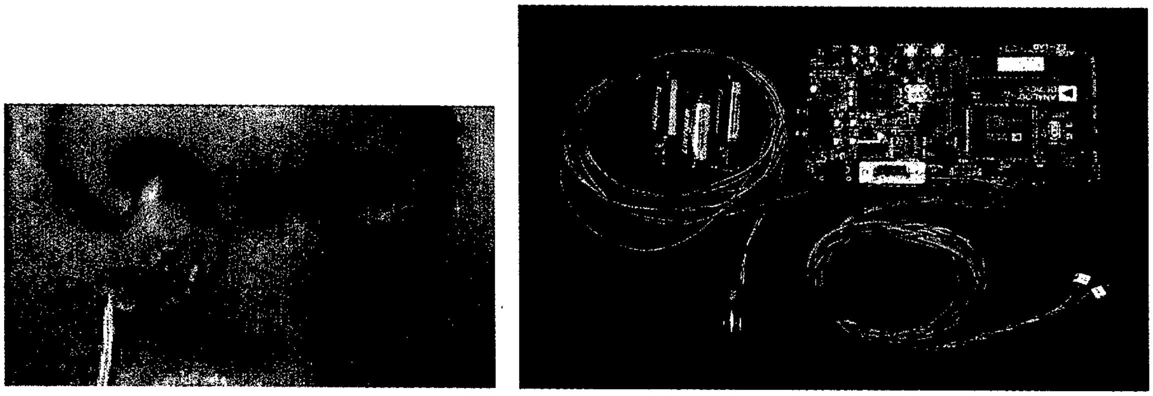


FIG. 13 LEFT---Nostril-air breathing cycle gating system improved lesion uptake in image

FOR TASK-5:

We continue the development of the image reconstruction and image processing. We have developed the software and methodology to study lesion detection in ultrahigh resolution PET cameras. We used this software to evaluate ways to achieve better lesion detection and published one peer-reviewed paper [14]. Four different image-reconstruction software and different image processing filters were implemented, tested and compared. For this research effort in this period, 2 abstracts were presented in conferences [15-16] and another peer-reviewed journal publication [17] was submitted.

KEY RESEARCH ACCOMPLISHMENTS

- The very complex transformable-PET mechanical design has been accomplished and 2 of the 12 detector heads (module) have been fabricated and put together and are being debugged and tested. The test results will be fed back for improving the construction of the rest of the 10 detector heads (both electronics and mechanical).

- All the 40,000 position-sensitive detectors have been constructed and tested. The results have been satisfactory.

- The very complex front-end electronics (HYPER) has been developed and fabricated. The programmable coincidence-detection electronics has also been developed and fabricated. These electronics are currently being tested with the 2 prototype detector head.

- A new detector tuning system has been developed. This system can tune all the detectors in the system in less than 1 minute, which is significant improvement to exisating commercial systems that take many hours to tune a PET with far fewer detectors

- A breathing-cycle movement-compensation method has also been developed to improve lesion detections in our system

- Four different types of image processing software have been implemented for the camera under construction.

REPORTABLE OUTCOMES

Peer-Reviewed Journal Publications (8 in print and 7 submit):

Uribe, J., Aykac, M., Baghaei, H., Li, H., Wang, Y., Liu, Y., Wong, V., Xing, T., Ramirez, R., Wong, W-H. Inexpensive Position Sensitive Detector Block for Dedicated PET Cameras Using 40 mm Diameter PMT in Quadrant Sharing Configuration. IEEE Transactions on Nuclear Science, *50*(3), 367-372, June, 2003.

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CONCLUSIONS

We have accomplished more than the scheduled tasks planned. The research led to 9 abstract presentations in scientific conferences, 7 papers submitted for peer-reviewed publications and 8 papers published in peer-reviewed journals. The very complex transformable-PET mechanical design has been accomplished, 2 of the 12 detector heads (module) have been fabricated and put together and are being debugged and tested. All the 40,000 position-sensitive detectors have been constructed and tested. The very complex front-end electronics (HYPER) has been developed and fabricated. The programmable coincidence-detection electronics has also been developed and fabricated. A new detector tuning system has been developed. This system can tune all the detectors in the system in less than 1 minute, which is significant improvement to existing commercial systems that take many hours to tune a PET with far fewer detectors. This auto-tuning invention can also be adopted by current commercial systems and allows the whole scanner to be retuned for every patient to assure that the scanner is in its optimal operating condition providing the highest quality images. Currently, commercial scanners are tuned once every few weeks to once every few months because of the long time required for tuning. A breathing-cycle movement-compensation method has also been developed to improve lesion detections in our system, which minimizes image blurring and artifacts created by patient movement during a scan. This methodology can also be used in a regular PET camera for improving cancer detectability. We have accomplished about 60% of the work needed to finish the proposed ultrahigh resolution transformable PET camera that can be transformed into a dedicated breast-PET camera with 15 times higher detection sensitivity and with 2-3 mm image resolution compared to the 5-6mm resolution of current commercial PET. This can lead to earlier and more accurate detection of breast cancer, which improves survivability.

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